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Early Hinode Observations of a Solar Filament Eruption

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Abstract.
We use *Hinode* X-Ray Telescope (XRT) and Solar Optical Telescope (SOT) filtergraph (FG) Stokes-V magnetogram observations to study the early onset of a solar eruption that includes an erupting filament that we observe in *TRACE* EUV images; this is one of the first filament eruptions seen with *Hinode*. The filament undergoes a slow rise for at least 30 min prior to its fast eruption and strong soft X-ray flaring, and the new *Hinode* data elucidate the physical processes occurring during the slow-rise period. During the slow-rise phase, a soft X-ray (SXR) sigmoid forms from apparent reconnection low in the sheared core field traced by the filament, and there is a low-level intensity peak in both EUV and SXRs during the slow rise. The SOT data show that magnetic flux cancelation occurs along the neutral line of the filament in the hours before eruption, and this likely caused the low-lying reconnection that produced the microflaring and the slow rise leading up to the eruption.

1. Introduction

Filament eruptions can be valuable "tools" to help understand basic processes occurring in solar eruptions. Filaments erupt when the field in which they are embedded explodes, frequently producing a solar flare and CME along with the ejection of the filament. By studying the motions of the filament prior to and during eruption, we can infer how the field is changing in the moments and hours leading up to eruption. It is during this time that the energy of the field, which is what ultimately powers the eruption, is starting to be released and converted into forms typically associated with solar eruptions.

In recent years we have observed closely a number of solar filament eruptions (Sterling, Moore, & Thompson 2001b; Sterling & Moore 2003, 2004a,b, 2005; Sterling, Harra, & Moore 2007; Sterling et al. 2007). It is common for the filament to start rising relatively slowly ($\sim 1 - 10$ km s^{-1}) prior to eruption ("slow-rise" phase), prior to rapid eruption (few $\times$ 10 — few $\times$ 100 km s^{-1}; "fast-rise" phase, "fast eruption," or sometimes just called "the eruption"). This phenomenon has been seen by many others also (e.g., Tandberg-Hanssen et al 1980; Kahler et al 1988; Feynman & Ruzmaikin 2004), although there are some eruptions that seem to not have a slow-rise phase (e.g., Kahler et al 1988). Understanding the slow rise can give clues to the onset mechanism of the eventual fast-rise phase.

Here we introduce our observations of a filament eruption occurring on 2007 Mar 2, using data from *Hinode,* specifically its Solar Optical Telescope (SOT) and its X-Ray Telescope (XRT). We also used EUV images from the *TRACE* satellite and magnetograms from MDI aboard the *SOHO* satellite. Sterling et al. (2007) give complete details of our observations of this event.

2. The Eruption of 2007 March 2

The filament was of moderate size ($\approx$ 50,000 km), and erupted on 2007 March 2 near 05:00 UT from a region that included active network and in the vicinity of a sunspot. Both the *TRACE* satellite and the Solar Optical Telescope (SOT) on the *Hinode* satellite have restricted fields of view, but both were observing the filament as it erupted. *TRACE* provided EUV images of the eruption, showing the filament in absorption. From SOT we obtained line-of-sight magnetic data from the Stokes-V component images from the instrument's filtergraph, and we also used soft X-ray (SXR) images from the *Hinode*'s X-Ray Telescope (XRT).

From the *TRACE* images, we can follow the filament's motions just before and at the start of the fast eruption. From the time the *TRACE* observations began, which was about 30 min before the onset of the fast eruption, parts of the filament were showing slow upward motions, similar to the slow-rise phase we have observed in our other studies. Motions of this filament, however, were relatively complex, with some portions remaining essentially stationary until the fast eruption occurred. It was also not as easy to track the filament's motions as in some of our other events, due in part to its orientation relative to our line of sight not being favorable. Another complication is that while erupting the filament underwent strong twisting motions, similar to that seen in a different event by Williams et al (2005). Nonetheless, we can determine that there are slow-rise motions prior to onset of the fast-rise phase; that fast rise started between 05:05 UT and 05:12 UT. During the slow-rise phase, a loop brightens in EUV, with the footpoint that brightens first located near where the subsequent flare arcade is born.

SXR images from XRT during the time of the slow rise show formation of a sigmoid structure. Then, during the time of the filament's fast rise, this sigmoid structure rushes away from the Sun during the fast-rise phase of the filament. The "sigmoid" (e.g., Rust & LaBonte 2005) appears to form in a manner similar to that reported on by Pevtsov, Canfield, & Zirin (1996), where two oppositely-oriented magnetic loops reconnected to form their sigmoid. In our case, we cannot see clearly the component loops prior to sigmoid formation, but by aligning the XRT images with magnetograms from SOT and MDI, we find that the polarities are appropriate for the formation of our sigmoid in this fashion. Moreover, the putative interaction site is at the location of the brightening footpoint of the EUV loop, and there is a brightening in the XRT images at the same time and location as that EUV brightening; thus both the EUV and SXR brightenings are very near the site of the expected reconnection. (We also observe that the XRT brightening occurs very close to or in the low-lying reconnection-product loops discussed below.)

Examination of time sequences of the SOT magnetograms shows that opposite-polarity flux converges beneath the filament in the hours preceding eruption, and

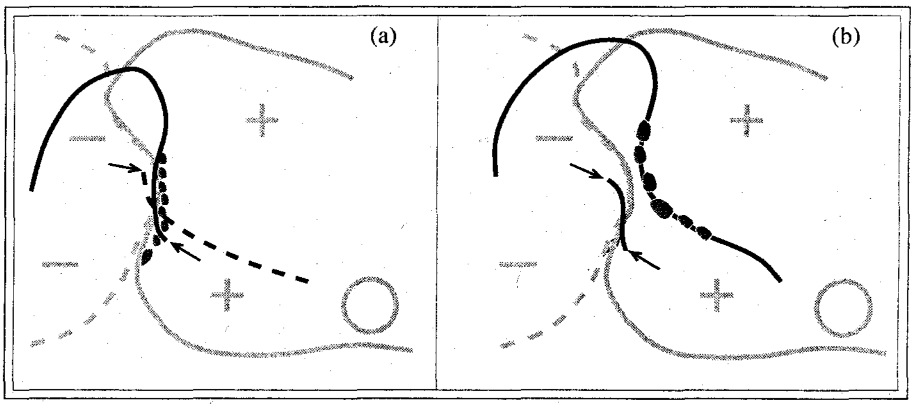

Figure 1.
Schematic depiction of the filament eruption of 2007 March 2, as described in the text. In both panels, grey solid and dashed curves outline magnetic regions generally of positive and negative polarities, respectively, with the circle being a positive-polarity spot. The shaded irregular patches represent filament material. In (a), thin solid and dashed lines represent selected field lines of magnetic loops that are about to mutually reconnect, with arrows pointing to footpoints of the dashed (left arrow) and solid (right arrow) loops. In (b) the loops have reconnected, with a sigmoid loop and low-lying loop (with arrows pointing to the latter's footpoints) being the structures resulting from the reconnection. Movies from XRT images (see online version of Sterling et al. 2007) show that the sigmoid (or related loops) escape explosively away from the region after its relatively slow development coinciding with the slow rise of the filament. We envision that the the filament material "rides" away from the Sun along with the escaping sigmoid, as pictured in (b).

measurements of the flux values from MDI show that the flux drops by a factor of three within five hours (the cadence of the available MDI data we used) of the eruption in a localized region around the filament; this is consistent with flux cancelation occurring in this region.

Figure 1 shows our interpretation of these observations. Prior to eruption (Fig 1a), the filament follows a prominent neutral line among enhanced magnetic network elements, with a sunspot off to the west. Convergence of field along the neutral line beneath the filament brings together the ends of opposing magnetic structures, resulting in reconnection between them. Figure 1a shows two field lines from these respective elements, with reconnection set to occur near the ends indicated by arrows. Two reconnection "products" result from this reconnection, as shown in Figure 1b, one being the sigmoid loop(s), and the other being a set of low-lying loops. We envision that the filament rides in the sigmoid loops, and the combination accelerates away from the Sun, eventually becoming part of an escaping coronal mass ejection (CME). Meanwhile, the lower-lying loops become part of the flare; this is essentially a version of the standard model for solar flares (Hirayama 1974 and derivatives; see, e.g., Forbes 2000, Moore & Sterling 2006).

Reconnection during the filament's slow-rise phase that leads to the formation of the sigmoid apparently occurs relatively slowly compared to that in

the fast eruption, as the sigmoid development in the XRT images occurs over at least 35 min (4:25 UT — 5:00 UT). This is consistent with what Moore & Roumeliotis (1992) termed "slow tether-cutting reconnection," and this seems to be responsible for the slow rise of the filament in this case. Magnetic changes also seemed to be responsible for the slow rise of filaments in other cases (e.g., Feynman & Ruzmaikin 2004; Sterling, Harra, & Moore 2007), and this may be a general cause of the slow rise in at least a class of filament eruptions. What we see here could be the tail end of a series of such reconnections, as described theoretically by, e.g., van Ballegooijen & Martens (1989). What is responsible for the switch from the slow-rise to the fast eruption, however, is still not clear from our studies (Moore & Sterling 2006; Sterling et al. 2007). Further investigations of filament eruptions using data from *Hinode* and other sources may be able to resolve these questions.

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